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FRAGMENTATION OF METEOR BODIES IN FLARES

by
V. I. Musiy and I. S. Shestaka

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FRAGMENTATION OF METEOR BODIES IN FLARES (DROBLENIE METEORNYKH TEL VO VSPYSHKAKH).

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Evaluation of the mass of individual fragments, the fragmentation time, and certain parameters required for plotting theoretical curves of meteor flare brightness. The brightness curves obtained for meteors fragmenting at a constant rate over a certain range of altitudes (from the commencement to the maximum brightness of a flare) are compared with meteor photographs obtained at the Odessa observatory.

V.P.

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FRAGMENTATION OF METEOR BODIES IN FLARES

by

V. I. Musiy and I. S. Shestaka

The appearance of flares on the light curve of a meteor has been connected several times [1-3] with fragmentation of the parent body into a large number of fragments. In this work, an attempt was made to evaluate the mass of a separate fragment, the time duration of fragmentation, and also the values of parameters $\sigma = \frac{A}{2EQ}$ и $K_1 = CA\delta^{-2}$, with which it is possible to obtain curves of meteor intensities in flares which agree with observations.

Two meteors with flares (No. 15 and No. 134) photographed at the Odessa Astronomic Observatory were selected for this purpose. Depictions of the meteors and selected stars for comparison were measured on a MF-2 microphotometer and so-called photometric sections were made in the areas of flares. The flare intensity curves obtained after photometric treatment were compared with theoretic curves which were computed by the method presented in this work.

As is evident from the observed intensity curves (Figs. 1-6), flares of both meteors have a comparatively sharp increase of their intensities and a slow decrease of them.

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If flares are considered to be instantaneous, then even considering photographic diffusion of the depiction, the theoretic calculations do not satisfactorily explain the character of the intensity curves (Figs. 1, 2). Therefore, a fragmentation model was accepted in which the separation of fragments from the parent body occurs not instantaneously, but over the course of some time: from the beginning of the flare to the moment of its maximum light. In this, it was accepted that the quantity of fragments produced in a unit of time (or occurring in a unit of path) remains constant.

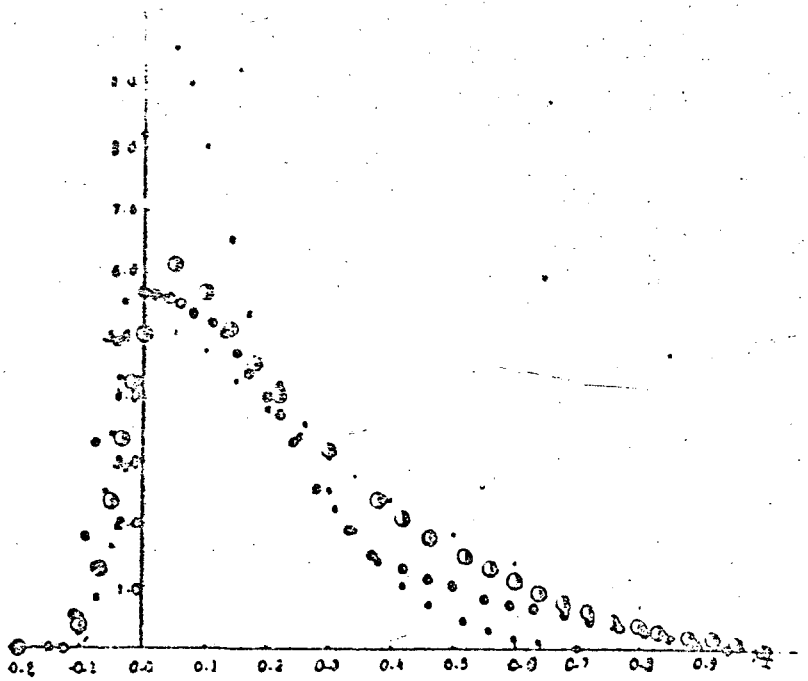

Fig. 1: Observed flare intensity of meteor No. 15 (circles with dots), computed for the case of instantaneous fragmentation: for fragments with an initial mass $m_o = 10^5$ g (crosses) $5 \cdot 10^{-6}$ g (black and white circles), and 10^{-6} g (dots). Abscissa -- distances in km; ordinates -- light intensity in joules/sec.

We will consider that the basic equations of meteor physics are justified for a separate fragment. For the sake of simplifcation, it can also be assumed that the separating fragments have an identical shape and equal initial masses.

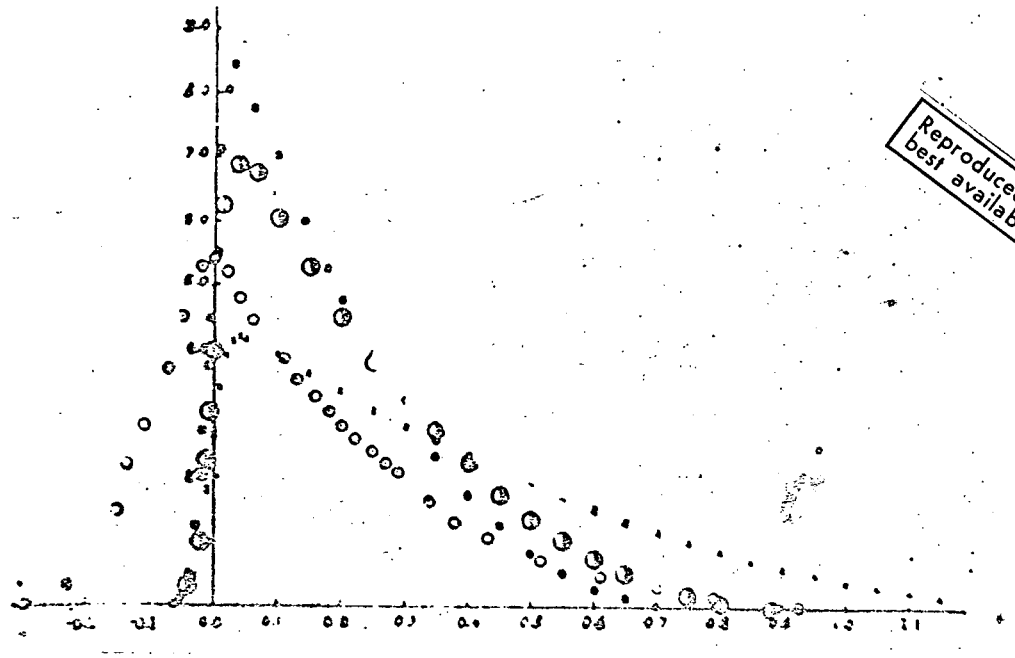

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Fig. 2: Same as Fig. 1, meteor No. 134.

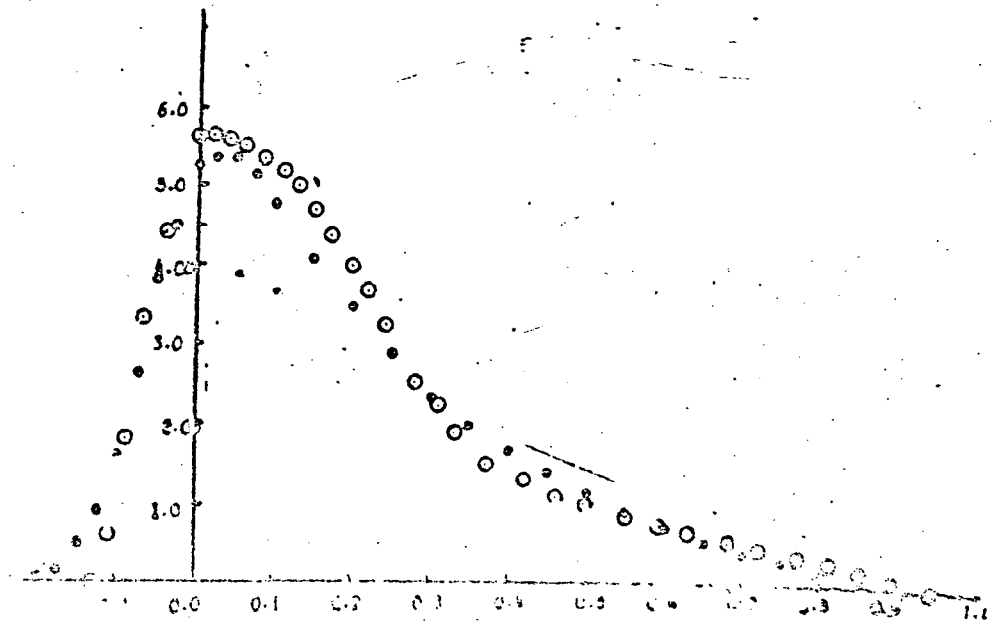

Fig. 3: Same as Fig. 1, meteor No. 15, constant fragmentation, $m_o = 5 \cdot 10^{-6}$ g.

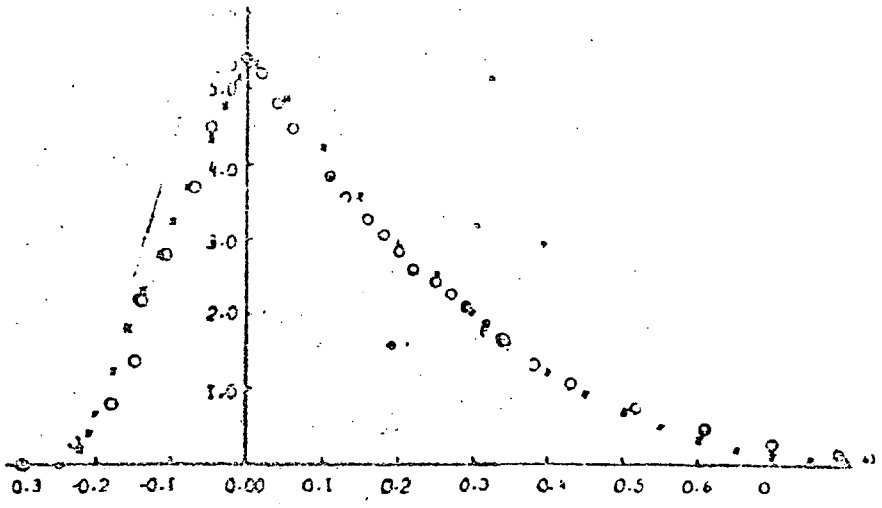

Fig. 4: Same as Fig. 1, meteor No. 134, constant fragmentation, $m_o = 2 \cdot 10^{-6}$ g.

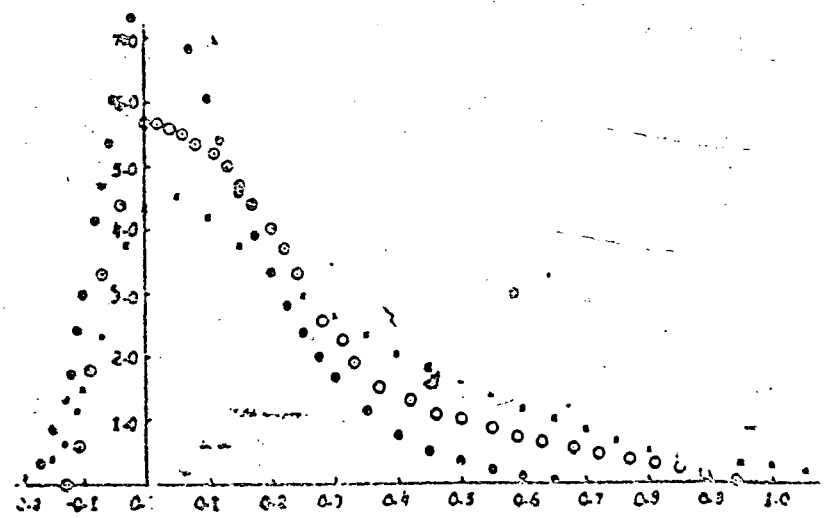

Fig. 5: Same as Fig. 1, meteor No. 15, even fragmentation.

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The intensity of brightness for any fragment in this case can be written in the following form: $I_p = \frac{\tau_o}{2} \sigma \cdot K_1 \cdot \rho \cdot m_o^{\frac{1}{3}} v^6 \exp\left[\frac{1}{3\sigma^2}(v_o^2 - v^2)\right]$,

where τ_o -- coefficient of luminescence, $\log \tau_o = -9.30$, [4]

σ -- coefficient of ablation,

Γ -- coefficient of deceleration,

A -- coefficient of form, for a sphere, A = 1.21, [5]

Q -- heat of vapor formation, $Q = 8 \cdot 10^{10}$ erg/g, [5]

ρ -- density of the atmosphere at height H,

m -- mass of the fragment at the moment in time t,

v -- velocity of the fragment at the moment in time t,

the index "o" relates to the moment the flare begins. Values of atmospheric density ρ are taken from the VSA-60 [table of time standard atmosphere, 1960]. [6].

Original data obtained as the result of geometric and photometric treatment are presented in Table 1. The mass of the separating fragment was evaluated by us according to the Smith method [2]: $m_o = \left[\frac{1}{3} \frac{\Lambda A}{2Q\delta^{\frac{2}{3}}} \cdot \frac{v^2}{\cos z_R} \cdot \int_{H_k}^{H_o} \rho dH\right]^3$.

Here Λ -- coefficient of heat extraction, δ -- density of the fragment substance, H and H_k -- height at beginning and end of flare. In both cases, the mass turned out to be on the order of 10^{-6} g.

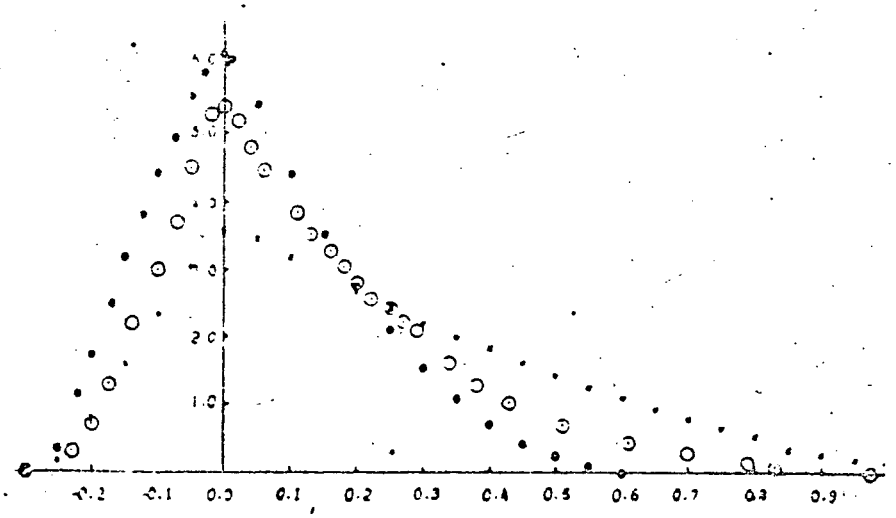

Fig. 6: Same as Fig. 1, meteor No. 134, constant fragmentation.

Table 1.

a. Номер метеора	15	134
b. Дата	27.08 1957 г.	30.07.1959 г.
c. v_o, км/сек	24.60	56.74
d. H_o, км	79.00	89.10
e. ρ_o, г/см³	2.5×10^{-8}	4.3×10^{-9}
f. $\rho_o v_o^2$, бар	1.4×10^5	1.38×10^5
g. $m_{всп}$, г	2.626	0.816
$\cos z_R$	0.87	0.72

Key: a. Meteor no.
b. Date
c. v_o, km/sec
d. H_o, km
e. ρ_o, g/cm^3
f. $\rho_o v_o^2$, bar
g. m_{flare}, g

We will consider that the investigated meteors are stony ones. In this proposition, $\Lambda = 1$, $\delta = 3.4$ g/cm^3. Paying attention to the fact that in very small bodies moving with sufficiently high velocities, Γ may be greater than one during their intensive vaporization [5], we will set $\Gamma = 1.5$. Then, $K_1 = 0.8$ g$^{-2/3}$ cm^2 and $\sigma = 4.15 \cdot 10^{-12}$ sec/cm^2.

From observations according to the known formula

$$m_{fla} = \frac{2}{\tau_e v^3} \int_{t_k}^{t_o} I dt,$$

where t_o is the time of the flare beginning and t_k is the time of the flare end (disregarding the change in velocity during the time of the flare duration), it is easy to obtain the photometric mass giving off light during the flare. We review the flare as the result of separated fragments glowing. Therefore, the average value of intensity conditioned by the parent body should be computed from each observed intensity value during computation of m_{fla}. Knowing the total mass of the fragments burned off during the flare and the mass of a

separated fragment, it is easy to obtain the number N of fragments of a given initial mass which separated from the parent body. Considering that the process of separation takes place from the moment the flare begins to the moment when intensity reaches its maximum, it is possible to judge the time of the meteor's fragmentation in the flare or the path Δs over the course of which its separation takes place.

The left portions of the observed curves of intensity during flares (Figs. 3, 4) are not explained by photographic image diffusion alone. We therefore selected path Δs in such a manner, using Δs and diffusion, as to obtain theoretic curves which satisfactorily describe the observations.

It can be more simply considered that fragmentation is even: this means that the number of fragment separations taking place in one cm, $\mu = \frac{N}{\Delta s}$, must remain constant. Then each unit of length of a fragmented material emits light energy equal to $\mu \cdot I_p$ in one second. This is a linear intensity. However, on the photograph in each point of the image, there is also a glow from its neighboring sections. We therefore are not observing a linear intensity but a somewhat integral one $I_{\Delta s}$. In order to obtain $I_{\Delta s}$, the linear intensity should be integrated along the entire path on which fragment separation takes place:

$$I_{\Delta s} = \int_{s}^{s+\Delta s} \mu I_p \, ds.$$

The theoretic intensity $I_{\Delta s}$ obtained in this manner must be corrected for photographic diffusion according to the diffusion equation:

$$F(x) = \int_{-\infty}^{+\infty} f(x-\xi) g(\xi) \, d\xi,$$

where f(x) -- investigative function without considering diffusion,

F(x) -- function considering diffusion. The function $g(\xi) = \frac{h}{\sqrt{\pi}} e^{-h^2\xi^2}$ is the function of errors and is a measure of the distortion of a photographic

image of a precise object by the photographic emulsion. It can be obtained very closely from cross-sectional photometry of the meteor. The value h is the so called measure of dispersion. We conducted about 20 determinations of h for images of stars and meteors located as close as possible to the center of the frame. The values of h are included between 9.00 mm^{-1} and 30.00 mm^{-1}. For meteor No. 15, $h = 6.8\ mm^{-1}$ and for meteor No. 134 $h = 16.0\ mm^{-1}$ (in the region of flares).

We obtained theoretic curves I(s) for fragments with initial masses lying in the interval 10^{-6} to 10^{-5} g (all theoretic curves were corrected for diffusion, see Figs. 3-6).

The results obtained (Figs. 3 and 4) allow a conclusion to be drawn to the effect that the most probable formation with the selected values of parameters σ and K_1 is the formation into flares of fragments with initial masses of: $m_0 = 5.0 \cdot 10^{-6}$ g for meteor No. 15 and $m_0 = 2.0 \cdot 10^{-6}$ g for meteor No. 14..

However, the selection of parameters σ and K_1 for a given initial mass of the separated fragment does not have a single value. Good agreement is obtained between the theory and the observations for fragments of those initial masses as well as higher ones and with other values of parameters σ and K_1. Values of σ and K_1 for stony fragments depending on Γ and going into the same theoretic curves (Figs. 3-4) are presented below:

Γ	a. σ, сек/см²	b. K_1, $г^{-2/3}$ см²
0,5	$12,50 \times 10^{-13}$	0,26
1,0	$6,25 \times 10^{-13}$	0,53
1,5	$4,15 \times 10^{-13}$	0,80
2,0	$3,13 \times 10^{-13}$	1,04
3,0	$2,08 \times 10^{-13}$	1,60

Key: a. σ, sec/cm^2 b. K_1, $g^{-2/3}\ cm^2$

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Odessa Astronomic Observatory.

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